CYCLE TIME REDUCTION FOR NAVAL AVIATION DEPOTS

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ABSTRACT

We describe two simulation models for repair processes of aircraft in the Navy, and suggest ways to reduce cycle time and improve readiness. The models illustrate the effects of material availability and process redesign on repair cycle time and work-in-process inventory levels for critical components. Our results indicate that the Navy could significantly reduce repair cycle times of those components by increasing stock levels of relatively inexpensive repair parts and slightly modifying current repair processes.

1 INTRODUCTION

Air power is one of the primary stanchions supporting the U.S. global defense strategy. Its importance obliges high-tech weapons systems including modern aircraft, well-trained pilots, and reliable logistics support. The goal of Naval aviation logistics support is to maintain the highest possible level of readiness, commonly expressed as operational availability,

$$A_o = \frac{\text{uptime}}{\text{uptime} + \text{downtime}} = \frac{\text{MTBM}}{\text{MTBM} + \text{MDT}},$$

where MTBM is the mean time between maintenance, and MDT is the maintenance down time, which includes repair time and administrative and logistics delay times. Intuitively, operational availability is the fraction of time a weapon system is operational or mission capable. Clearly, operational availability can be improved by increasing MTBM (i.e., increasing reliability) or decreasing MDT (i.e., reducing repair time). Thus the two key issues to improve weapon systems readiness are reliability improvement and cycle time reduction.

From Little's formula (Little, 1961), reducing cycle time reduces pipeline inventory directly and proportionally. Cycle time reduction in a military logistics channel (repair depots, intermediate-level maintenance, inventory control points, and supply centers) means that more weapon systems are available at the fleets and fields, and also leads to significant savings in inventory costs.

The relationship between inventory levels and repair processes is troublesome in the Navy because it crosses physical, organizational, and financial barriers. Inventory managers strive to consolidate and minimize stocks of piece-parts to free up resources for other priorities. They also seek to get quick turnaround on repairable components in order to minimize pipeline inventory. The NADEP generally has different concerns, such as reducing costs by increasing worker efficiency and machine utilization. This leads to a natural conflict in repairables management: Inventory managers want short production runs to minimize pipeline inventory, while depot managers want long production runs to minimize repair costs. Because the organizations report to different authorities, integrated operations and goals have been illusive.

Modeling and simulation might be used to address these management challenges in two ways. First, models shown in this paper could be used as an educational tool to show each organization the effects of its behavior on the other. Graphics could be very useful in creating constructive dialog between the competing parties. Second, the models could be used to quantify some of the tradeoffs inherent in the inventory and repair processes. This could be very useful when discussing issues like stock levels, prices, and surcharges for premium service.

We describe research collaboration between the Naval Postgraduate School, Naval Air Systems Command, and Naval Aviation Depots on cycle time reduction to improve aviation readiness. Specifically, we describe the use of simulation modeling and other quantitative methods to help reduce repair cycle times at Naval Aviation Depots.

In section 2, we briefly describe Naval aviation maintenance and supply and its effect on readiness.

We present two simulation models for repair cycle time analysis in section 3, and conclude the paper in section 4.

2 NAVAL AVIATION MAINTENANCE

2.1 Levels of Maintenance

The Naval Aviation Maintenance Program divides maintenance into three levels: organizational level (O-level), intermediate level (I-level), and depot level (D-level), which are similar in structure to multi-echelon logistics support systems of commercial firms (e.g., Blanchard, 1998). To achieve economies of scale in maintenance equipment and personnel, levels of maintenance are progressively more capable, with D-level being the most capable.

O-level maintenance is performed at the site and typically involves simple repairs or the replacement of modular components. I-level maintenance involves more difficult repairs and maintenance, including the repair and testing of modules that have failed at the O-level. I-level maintenance for Navy aircraft is done at Aircraft Intermediate Maintenance Departments (AIMDs) ashore in naval air stations, or afloat in aircraft carriers.

D-level maintenance activities, called Naval Aviation Depots (NADEPs), ensure the continued flight integrity and safety of airframes and related flight systems throughout their service lives. This involves performing maintenance beyond the capabilities of the lower levels, usually on equipment requiring major overhaul or rebuilding of end items, subassemblies, and parts. The Navy operates three NADEPs in the U. S. (North Island, CA; Cherry Point, NC; and Jacksonville, FL) and fleet repair facility sites in Italy and Japan.

The depot repair cycle begins when an unserviceable depot-level repairable is turned in to the O- or I-level maintenance, and it ends when the item is recorded on the inventory control point records as being ready-for-issue (RFI). Depot repair cycle time includes shipping and processing time, accumulation time, repair time, time awaiting parts, and delivery time. Unserviceable items may remain in storage for extended times for various reasons. Recorded repair cycle time excludes this time in storage.

Based on 1995 Budget Estimate Submissions (Kiebler et al., 1996), the average depot repair cycle time is 86.8 days, with a resulting pipeline inventory valued at $4.4 billion. Applying Little's formula, pipeline inventory would be decreased by an average of $51 million for each day the cycle time is reduced.

2.2 Readiness, Maintenance and Supply

Aviation readiness is measured by computing fully mission capable (FMC) rates. The FMC rate indicates the operational availability of the aircraft in a unit; that is, the fraction of aircraft that are mission capable at any arbitrary time. When aircraft are partially mission capable or not mission capable, it is because of either maintenance or supply problems.

Aviation items, especially repairables, are very expensive to maintain. For example, each aircraft carrier carries onboard an Aviation Consolidated Allowance List (AVCAL) consisting of consumable and repairable items and subassemblies required to support the Air Wing for 90 days of wartime operations. A typical AVCAL consists of approximately 61,000 line items valued at approximately $266 million. Repairable items represent only 10 percent of the total line items but 90 percent of the total value of the AVCAL (USS Independence Shipboard Uniform Automatic Data Processing System Report 008, July 26, 1991).

Material readiness demands spares, but fiscal constraints have put pressure on the Navy to reduce inventory levels at AIMDs and stock points. The two-part solution is easier said than done: select a "better" mix of spares *and* reduce repair cycle time. Both tend to improve readiness for a given cost, or achieve the same readiness for lower cost.

The relationship between spares levels and cycle time is a key to understanding how to achieve higher readiness at lower cost. To illustrate, suppose that an aircraft squadron operates 20 single-engine aircraft and maintains its own repair facility. Suppose that engines failures follow an exponential distribution at a rate of one per aircraft per 100 hours, and the time to repair is exponentially distributed with a mean of 5 hours. When the engine fails, it is removed from the aircraft and a spare engine is installed, if available. The faulty engine is sent to the repair shop for repair. If a spare is not available when an engine fails, the aircraft is grounded until a spare engine is repaired and delivered.

We implemented the "finite source population with spares" queueing model from Gross and Harris (1985), and calculated A_o for this example (see Figure 1, Scenario 1). This scenario shows that additional spares provide higher A_o, but the marginal increase in A_o decreases as the number of spares increases; that is, the value of the first spare is greater than that of the 10^{th}. For this example, we achieve an average operational availability of 0.841 with no spares at all. With an additional spare, A_o increases by 0.022 (0.841 to 0.863), while the tenth spare in-

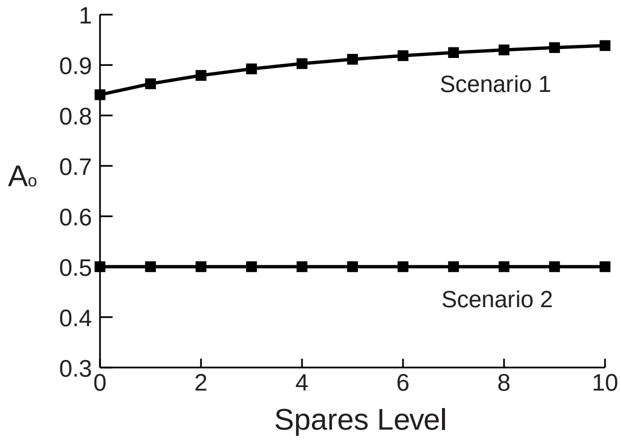

Figure 1: Operational availability for different repair times.

creases A_o by 0.004.

For Scenario 2 we increased the average repair time from 5 hours to 10 hours. Note that A_o remains constant even with additional spare parts, because the maximum failure rate (when all the aircraft are in operational mode) is 0.2 per hour (0.01 x 20 aircraft), while the repair rate is only 0.1 per hour. This implies that, in the long run, 50% of the aircraft will be inoperable, regardless of the number of spares in the system (see Kang 1993 for details). Thus spares levels and repair cycle time must be considered together when attempting to improve material readiness.

During the past 30 years the military has been slowly implementing spares methodologies based on the METRIC models described in Sherbrooke (1992). Rather than the traditional approach to inventory problems that minimize holding and ordering costs for individual items subject to a service level, readiness based models seek to maximize A_o for multiple items directly and simultaneously, subject to a budget constraint. These models are important to military systems because they treat all of the significant components in a weapons system together, in order to achieve the singular objective of maximizing A_o. Implementation of these models requires detailed, accurate information about the reliability of components, but the rewards have been worth the effort in many systems: For example, Sherbrooke (1992) reports inventory investment being cut nearly in half with no degradation in readiness during a test for the Air Force.

3 THE COMPONENT PROGRAM AT A NADEP

Naval aviation readiness is directly linked to the availability of material for timely, cost-efficient repair of aircraft. A NADEP's primary function is to overhaul and repair aircraft and their components, which includes restoration of the designed levels of performance, reliability, and material condition. Activities span complete rebuild through reclamation, refurbishment, replacement, adjustment, servicing, and replacement of system consumables.

In this section, we present two simulation models for turn-around-time (TAT) reduction analysis. We first develop a simulation model of aviation logistics flow with graphics animation written in Arena (Kelton, 1988). The model describes the flow of aircraft from the squadron of an aircraft carrier to O-level, I-level, and D-level maintenance with a what-if analysis user-interface.

A screenshot of the animation is shown in Figure 2. Aircraft on the top deck of the carrier are operational; those below decks are in repair. If the faulty component cannot be repaired on the ship, it is sent to the NADEP ashore. The graph at the bottom right shows parameters of interest, including A_o over time. The purpose of the model is to educate personnel in the logistics community on the importance of cycle-time reduction to fleet readiness. This model will be presented with animation during the conference.

The second simulation model describes the NADEP component repair program, which is a complex job-shop environment. For example, at NADEP North Island, 22,916 unique items are overhauled or repaired, supporting many types of aircraft, including the F/A-18 and F-14. In general, a relatively small number of these items are major readiness degraders and high cost items. We define readiness degrader to mean any item that, due to its shortness of supply, has caused fleet aviation readiness to be degraded.

To demonstrate the use of the model, we pick one critical readiness degrader and develop a simulation model for its entire repair process. The model can be used to evaluate process changes that could reduce repair cycle time and lead to inventory savings.

We reviewed the NADEP North Island production status information system to identify major readiness degraders. We chose an alternating motor used on a hydraulic actuating valve for anti-submarine aircraft. The repair process is divided into four phases:

PHASE I: Transfer to induction A quarterly induction quantity for any component is determined primarily by the scheduled negotiations be-

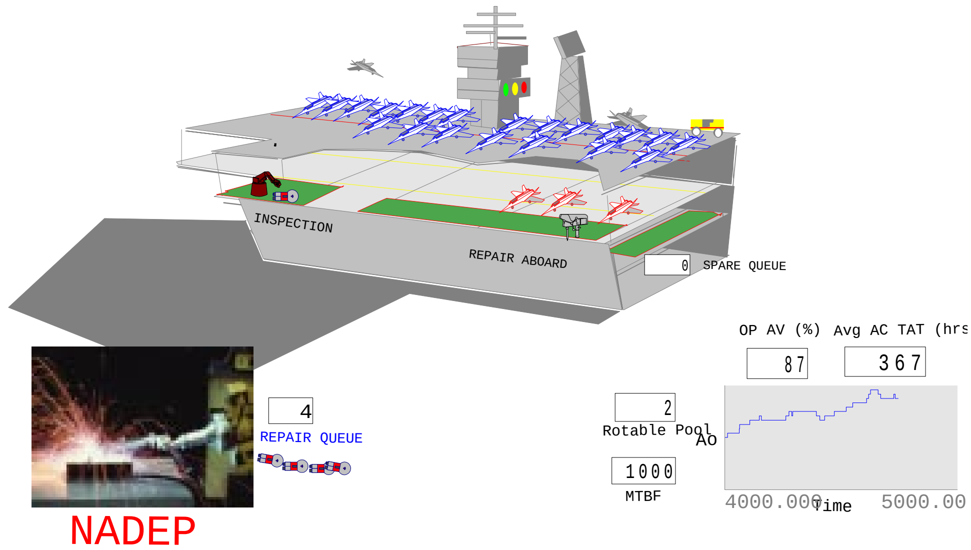

Figure 2: A screenshot of the logistics flow model in ARENA

tween Navy Inventory Control Point-Philadelphia (NAVICP-P), which is responsible for aviation repairable items, and the NADEP. When the Defense Distribution Depot (DDD, the warehouse of repairable items) receives induction requests from the NADEP, the component is pulled from the available inventory of faulty components (referred to as *F-condition* assets) and staged for custody transfer to the NADEP. The DDD pulls F-condition assets on the 11 a.m.–7:30 p.m. shift and stages them for transfer to the NADEP the following morning at 7 a.m. Phase I is complete when the NADEP accepts custody of the material and matches it with the applicable paperwork. Then it is sent to the NADEP dispatch system, the routing activity between repair locations. Currently, trucks make facility-wide scheduled material movements at 9:30 a.m. and 1:30 p.m., Monday through Friday. Additional movements throughout the day occur on an as-needed basis.

PHASE II: Shop processing Once the component arrives in the repair shop, it is sent to the responsible work centers where technicians conduct tests, fault isolation, and repair. After repair, they document the repair actions and perform final testing before quality assurance inspection. Upon passing, the component is processed for routing to another shop for any other required repairs. This process is repeated until all the required repair processes are completed. Then the component is delivered to the dispatch center for transport.

PHASE III: Painting The item is routed to a different building (let's call it Building 2, vs. Building 1 where the repair shops are), for painting. Items requiring paint are routed and processed through the Building 2 dispatch center and arrive at the paint shop queue. The paint shop routinely processes all items in its queue during a single work day. However, an item must be dried and cured before being transferred to the next phase.

PHASE IV: Delivery processing and custody transfer to storage The component returns to the dispatch center for a return trip to the cognizant repair shop in Building 1. The sole purpose for returning to Building 1 is delivery processing. At this point, actual repair TAT and WIP are measured, and the item becomes RFI. It is packaged and routed to the DDD warehouse for stocking, and custody is transferred back to DDD.

3.1 Simulation Model

Our simulation model includes the entire repair process for the alternating motor described above. Some of the data were extracted from the NADEP information system others were collected through interviews of foremen and artisans at the shop. The model is written in the simulation language ARENA with graphics animation. The simulation results for TAT closely approximate figures obtained from the fourth quarter of FY-97: actual TAT was 26 days, while the model estimated 23.47.

Table 1: Summary of the simulation results. Values in the parentheses are percentage reduction over the baseline scenario. TAT values are in days.

	Embellishment			
	Base	1	2	3
TAT	23.47	15.82	22.05	23.48
		(-32.6%)	(-6.05%)	(0.00%)
WIP	22.56	14.66	20.34	22.08
		(-34.9%)	(-9.84%)	(-2.01%)

We made the following embellishments to find potential savings in TAT and inventory:

1. Material availability: Increase initial availability of material required for repair from the current 20% to 50%, thereby reducing the time spent waiting for parts.

2. Change of delivery processing: Conduct the delivery processing function in Building 2 instead of Building 1, thereby eliminating the required movement of the component back to the responsible shop prior to custody exchange.

3. Relocation of Quality Assurance (QA) inspectors: Move QA inspectors into Building 2, conduct QA inspection after painting, and eliminate the current QA inspections in Building 1.

These three changes were made individually and twenty replications were made for each scenario to analyze for potential savings. Table 1 shows the results for repair TAT and WIP.

3.2 Analysis

3.2.1 Material Availability

The material requirements process requires an artisan to requisition needed material and, if it is not in stock, to place the component into a delay status until all the piece-parts are available to complete the repair. The foreman in that shop estimated that material is available in local stock for this alternating motor an average of only 20% of the time. He reported that this is a typical service level for many repair piece-parts. For the remaining 80%, there is currently an average waiting period of 20 days for receipt of all material requirements.

If the equipment specialist determines that time spent awaiting parts will exceed 45 days, the component is transferred from M- (under repair) to G-condition (awaiting parts), is removed from WIP inventory, and TAT resets to zero. When the component is re-inducted into the repair process following receipt of the required piece-parts, it must repeat all of its previous steps.

Processing delays due to not having material available obviously increase TAT and directly increase pipeline inventory investment. Furthermore, the cost of the piece-parts necessary for repair is negligible compared to the procurement cost of the component, in this case an alternating motor. What benefit might we realize by stocking more piece-parts in the NADEP?

The simulation results (Embellishment 1) in Table 1 indicate that an improvement in material availability from 20% to 50% could yield reductions in TAT of 7.65 days. Increased material availability results in component WIP savings because components wait less time for piece-parts. With above reduction in TAT, average WIP level would drop by 7.90 units (a 35% reduction).

Based on the unit retail cost of $6,310 for the motor, reducing the cycle time of the repair process by 7.65 days could potentially reduce the value of the WIP by $50,000. The costs of piece-parts inventory are likely a fraction of this amount. If similar pipeline inventory reductions could be achieved by increasing the repair parts availability, the Navy could achieve significant inventory savings. For example, in FY-97 the value of the NADEP North Island component WIP inventory was more than $200 million. A 35% reduction in pipeline inventory leads to more than $70 million in WIP reduction.

3.2.2 Delivery Processing

Delivery processing records the completion of the repair process and administratively credits the responsible shop with completion of the repair. Current NADEP business practice calls for delivery processing to be conducted at the responsible shop. Following completion of repairs, QA, and routing for painting, the item travels back through the transportation network to the responsible shop for delivery processing.

In reviewing the process, we observed that the majority of time required to conduct delivery processing is the transit time back to the responsible shop, handling at the shop's dispatch center, and repetition of these steps following the processing. From Table 1, handling the items in the current fashion adds approximately 1.4 days to the TAT for an item. If delivery processing and credit to the responsible shop could be conducted immediately following painting and the item routed directly to custody exchange, approximately 1.4 days could be eliminated in the repair pipeline time. This reduction in TAT leads to a reduction in average WIP inventory of 2.2 components.

3.2.3 Relocating QA Inspectors

QA inspections are conducted randomly during the repair process. The randomness associated with the inspector's schedule and the completion times for repairs causes items to wait in a queue for the inspector's arrival. Locating a QA inspector at the paint shop dispatch center and conducting all QA inspections there could reduce the randomness of QA inspections, allowing items to flow straight from repair to paint shop without the queue time. Failure rates at QA inspections are negligible, so returns to the responsible shop for reprocessing would be rare.

The TAT reduction associated with relocating QA inspections is negligible as shown Table 1; however, when coupled with other incremental gains, it could potentially contribute to TAT and WIP reductions.

4 CONCLUDING REMARKS

Although modeling and simulation (M&S) has been used in the military communities for a long time, the emphasis has been on war-gaming simulation. We have illustrated the benefits of M&S for military aviation logistics applications. Recent developments in M&S technology, especially graphics animation, have made simulation implementation easier because decision makers quickly identify with the problem, model, and proposed solutions.

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